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Procedia Environmental Sciences 10 (2011) 2775 – 2782

Procedia Environmental Sciences

2011 3rd International Conference on Environmental Science and Information Application Technology (ESIAT 2011)

A Multi-Wavelength Canopy LiDAR for Vegetation Monitoring: System Implementation and Laboratory-Based Tests

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Abstract

The instrumentation of a Multi-Wavelength Canopy LiDAR system (MWCL) for vegetation monitoring was tested by using low power, solid and semiconductor lasers. The proposed instrument takes measurements at four wavelengths which are highly interrelated to the chlorophyll concentration, Nitrogen content and other biochemical properties. The receiver consists of four channels, which would capture the LiDAR back-scatter signals of the four wavelengths separately at 556nm, 670nm, 700nm and 780nm. It is shown that the MWCL could not only provide structure information on vegetation canopy, but could also pick up the LiDAR intensity information. A 3-D reconstruction procedure based on the LiDAR back-scatter waveform has been done, and a supervised classification based on the intensity data is also accomplished. The results showed that the MWCL was able to significantly improve the retrieval accuracy of photosynthetically active biomass opposed to using a single-wavelength LiDAR alone.

Keywords: Multi-wavelength, LiDAR intensity, vegetation monitoring

1. Introduction

Airborne laser scanning (ALS) is a well- established technique for the measurement of surface topography [1,2] and for the 3-D characterization of targets, such a technique has combined laser detection, GPS and together with INS. ALS could acquire surface information effectively especially in getting the mass production of DEM and DOM. Compared with traditional methods, ALS provides an active way to acquire data in remote sensing. However, as these LiDAR applications mentioned above just make use of single wavelength laser emitter to work and lack of backscatter intensity information, they can hardly provide physiological characteristic of ground features. This makes it a new limitation for

doi:10.1016/j.proenv.2011.09.430

earth observation. Thus, extending single-wavelength LiDAR into broadband spectral has become a suitable next step in the development of more effective surface and target detection.

One of the important issue in remote sensing today is that how to reduce uncertainty in the retrieval of biochemical canopy properties. Early attempts of fusing LiDAR range data together with hyper-spectral images make it a possible way to solve this problem[3]. However, as the hyper-spectral image data are mostly derived by passive sensors, the quality of the fusion affected by the weather, shadow, and background noise etc.

As hyper-spectral remote sensing has great ability in detecting the characteristic of ground objects and LiDAR is an effective and active way on earth observation, a concept of a multi-wavelength LiDAR has been proposed recently. Rall and Knox described a nearest dual-wavelength spectral ratio biospheric LiDAR system [4]. Tan and Narayanan developed a multi-spectral polarized LiDAR [5], these two multi-spectral LiDAR system mainly used for distinguish woody and non-woody features and cannot monitoring vegetation growing status or other biochemical properties. Morsdorf and Nichol et al simulated a four wavelength canopy LiDAR which could monitoring forest canopy growing status [6]. However, a real MWCL system used for vegetation monitoring as well as structure reconstruction has not been seen so far. According to Song's research [7] on band selection, we proposed a four wavelength LiDAR system to accomplish the vegetation monitoring test. The capabilities of such a MWCL system have been testified in this paper.

2. System Implementation

A laboratory based prototype of MWCL has been developed by using low power, solid and semiconductor lasers. The system mainly consists of three parts: (i) the laser source and beam combination sub-system, (ii) the optical receiver light splitting sub-system, and (iii), the data acquisition and processing sub-system. The block diagram of the MWCL is shown in Fig. 1.

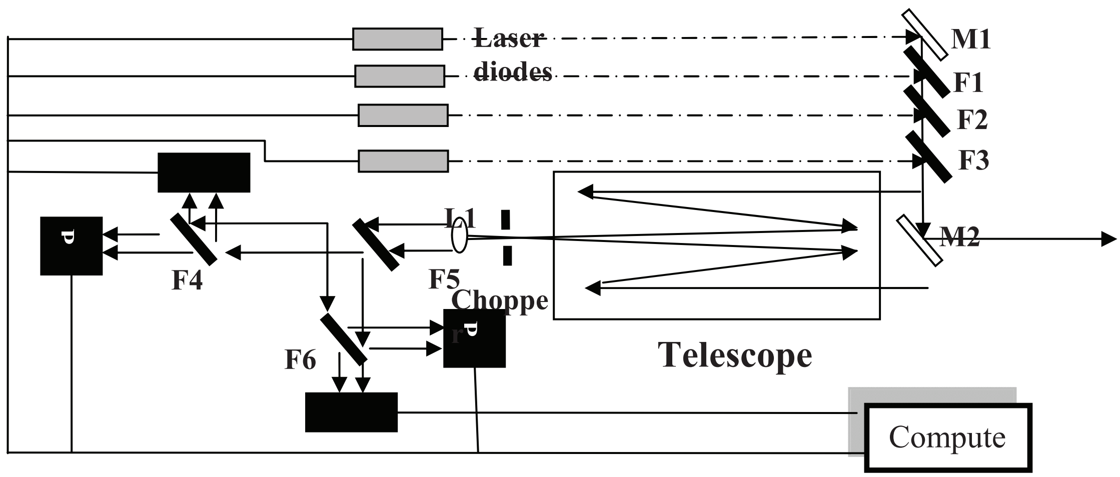

Fig. 1 optical layout of Multi-Wavelength Canopy LiDAR

The four laser diodes, two of which are solid while the other two are semi-conductive, send out four laser beams simultaneously and finally been combined to one single beam after passing through couples of special lens. The backscattered light is collected by a 20 cm diameter Schmidt-Cassegrain telescope that has an adjustable iris at its focus to limit the receiver field of view, then the photonic signals are amplified and converted to electric signals throughout the PMTs, and outputs from the PMTs are A/D converted by a digital oscillograph. Finally, the signals are send and stored in a computer hard disk, preparing for subsequent data processing. The prototype MWCL demonstration system is shown in Fig. 2.

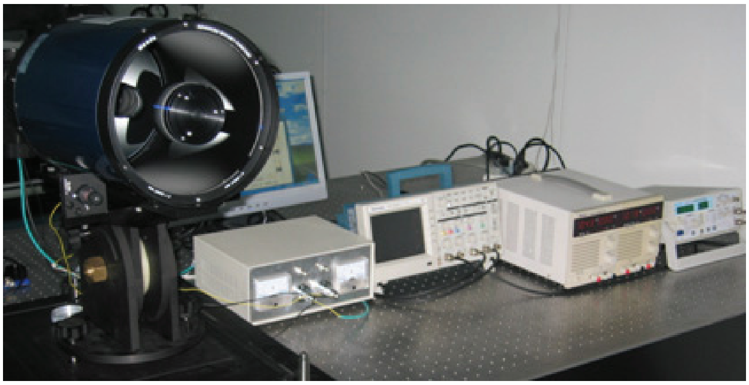

Fig. 2 MWCL demonstration system

3. System Calibration

The LiDAR equation can be expressed in a number of forms, different lidar equations against with different backscatter/ reflect mechanisms, totally there are two types: the opaque targets equation and the soft targets equation. As the samples we employ in the experiments are all opaque ones, here we choose the LiDAR equation as Eq. 1[Wagner et al. (2006)]:

$$P_r = \frac{P_t D_r^2}{4\pi R^4 \beta_t^2}\sigma \tag{1}$$

where Pt is the transmitted power, Dr is the aperture diameter of the receiver optics, R is the range, and β_t is the transmitter beam-width. All target parameters are combined into one parameter, the backscatter cross-section σ, which is defined as Eq. 2:

$$\sigma = \frac{4\pi}{\Omega}\rho A_s \tag{2}$$

Where Ω is the angle defining a back scattering cone due to surface roughness, ρ is the reflectivity of objects and A_s is the illuminated area of the scattering element. Simply, we assume that the elements act as Lambertian scatters, which means that the directional effects of Eq. 2 can be neglected as the incoming radiation is scattered uniformly across the hemisphere. Thus, to obtain the real LiDAR reflectance, the received intensity at each transmitting laser wavelength obtained from Eq. 2 needs to be calculated with a calibrated standard white board in the same way. For the MWCL system, the reflectance of the laser light at the four wavelengths was calibrated simultaneously.

4. Laboratory-based tests and Results

To test the capability of MWCL system on capturing canopy structure and monitoring vegetation growing state, LiDAR measurements have been taken during September and November 2010. Two boxes that have different shapes were chosen as 3-D reconstruction samples and another four kinds of testing elements was selected for intensity measurements. All the measurements were done the same as airborne laser scanning by simulating its way to get a 3-D image, which contains not only structure information, but also the LiDAR intensity information. The MWCL instrument was operated horizontally from a rooftop laboratory 20 meters from the target. Laser diodes emitted at the four wavelengths synchronously with a pulse repetition frequency of 800 Hz.

The scanning was done by this way: the MWCL system scans in the horizontal path point by point and after one line's scanning accomplished (the scanning angular could be designed by controlling software system), an automatically lifting machine will raise a constant interval, which similar to the flying direction according to the ALS. The horizontal and vertical paths are corresponding to X and Y coordinates, separately, while the range value is corresponding to Z axis. Thus, by doing the scanning this way, we can get a 3-D dataset which could be used for 3-D reconstruction. The 3-D reconstruction results are shown in Fig. 3(b).

Fig. 3(a) real scanning scene

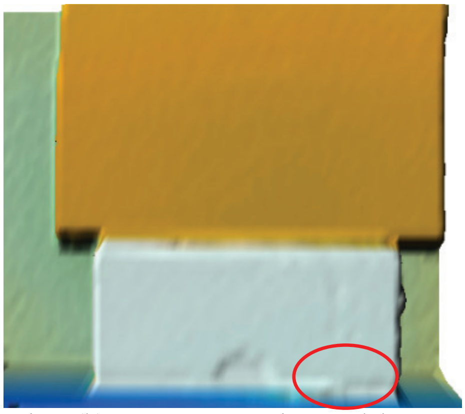

Fig. 3(b) 3-D reconstruction model using MWCL rang value

The results shows a highly special resolution about 2mm as the marked area in Fig. 3(a) was about 2mm deep (measured by a micrometer) could be clearly identified in the reconstruct model as marked red in Fig. 3(b). Other parts of the reconstruction image also show the MWCL's high quality on spatial detection.

Another experiment was done to test the MWCL's capability on vegetation monitoring by using intensity back-scatter signal. The scanning way was the same as 3-D scanning, to make it simple , we just scanning a single line when acquiring the intensity value as the other lines were similar to this line and it could represent the optical properties quite well. The scanning scene and line were shown in Fig. 4.

Fig. 4 intensity scanning line, the red line represents the scanning path

Before we do the scanning, a calibration was done by measuring a standard whiteboard, whose reflectance was define as criterion. Then the intensity data could be calculated to reflectance data. A NDVI profile was then calculated by two of the four wavelengths' reflectance. The NDVI was calculated according to Eq. 3:

$$NDVI_{laser} = \frac{\rho 780 - \rho 670}{\rho 780 + \rho 670} \tag{3}$$

The LiDAR back-scatter intensity signal is shown in Fig. 5(a) and the NDVI profiles is shown in Fig. 5(b)

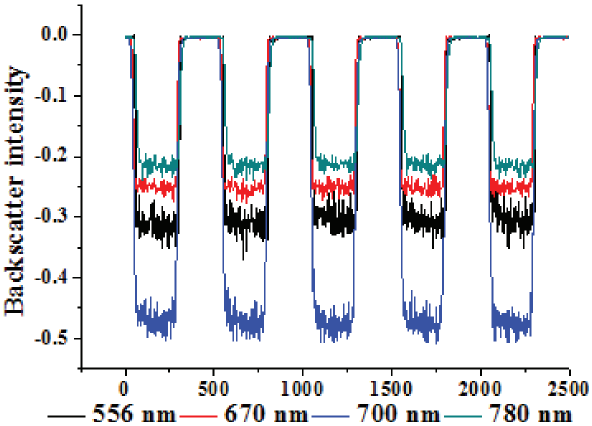

Fig. 5(a) back-scatter intensity signal

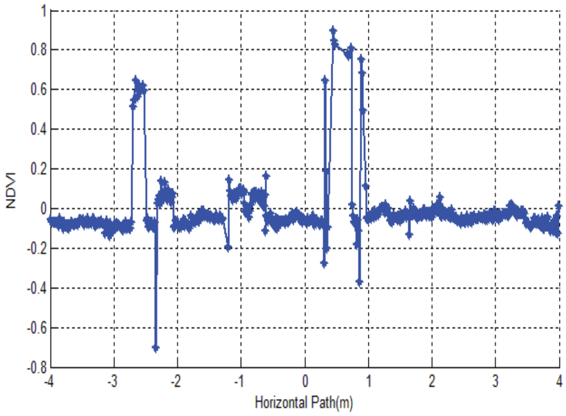

Fig. 5(b)NDVI profile according to scanning line

All these signals are pre-denoised by a special wavelet denoise method [Lv Lilei et al]. The purpose of this step is to reduce noise effect and increase signal to noise ratio (SNR). In the NDVI profile (see Fig. 5(b)) we can get two obvious peaks at horizontal path about x=3.4 and x=0.8, where Wet grass land and Broadleaf tree at. It means that NDVI values calculated by the MWCL back-scatter waveform are much higher (about 0.6~0.8) than any other positions, where no-woody elements exist. The structure profile is also derived by the MWCL system in this experiment, shown in Fig. 6:

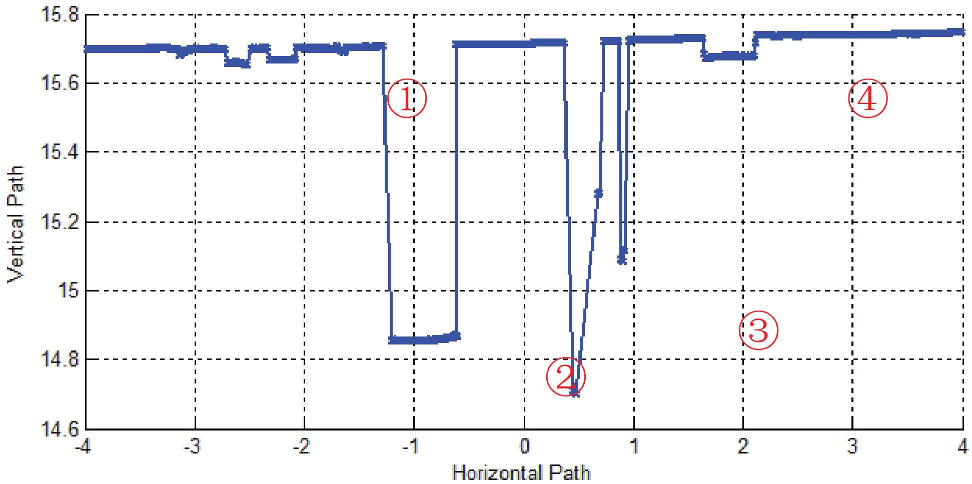

Fig. 6 structure profile get from MWCL system the four peaks refers to four kinds of samples in Fig. 4

For further data processing, we tried to make a simple classification using k-means method. During the classification, six kinds of variables are employed, which are reflections at four different wavelengths, NDVI values and distances. The class number was set to 4 and the classification result is shown in Fig. 7:

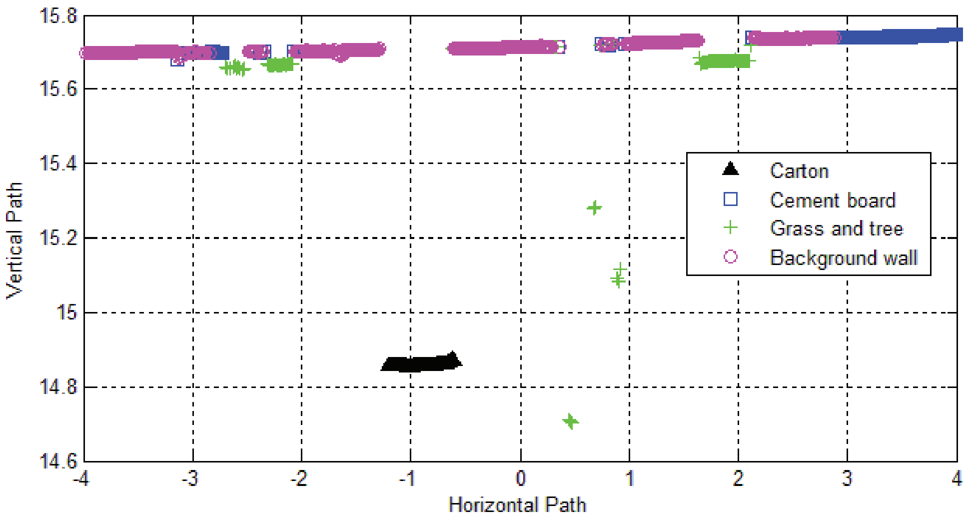

Fig. 7 classification result using k-means method

The dataset was mainly divided into four classes, during the classification, the wet grass land was mixed into broadleaf tree, this is not hard to understand as the variables used for k-means classification consist of NDVI, distance and reflections of four wavelengths. From Fig. 5 and Fig. 6 we can see that these 6 variables between wet grass land and broadleaf tree is quite similar. The other three classes gathers well.The classification results show the MWCL system's capabilities and advantages in earth observation, its capability of identifying different objects, especially woody and non-woody, is much higher than a single wavelength LiDAR systems.

5. Discussion and conclusion

In this paper, a prototype of a Multi-Wavelength Canopy LiDAR system was tested to identify its capability on vegetation monitoring and feature classification. The results show that the MWCL system could not only capture the structure information of the objects (vegetation included), but also could get the intensity information, which was converted to reflectance after a standard calibration. Such a concept of the MWCL system was testified to be effective in distinguishing woody and non-woody features, as well as objects with different structures. Still, its potential capabilities on quantitative vegetation monitoring needs to be tested, and the more reasonable and effective way in calibration system is also in consideration.

6. Acknowledgement

Paper supported by Major State Basic Research Development Program (973 project) (2009CB723905); 863 Project (2009AA12Z107); NSFC(20106190201000150); NSFC(10978003); 973 project (2006CB403701); NSFC(40871171); Program for New Century Excellent Talents in University (NCET-07-0629)

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